Appendix I – Willamette River Floods and Hydrology

Introduction

Portland Harbor is located on a tidal river. Modeling flows and bedstresses correctly requires that both the tidal and fluvial forcing be correct for the conditions modeled, including during floods up to an including at least the 100-year flood. This is particularly important for evaluation of the stability of contaminants in the bed. Thus, the purpose of this Appendix is to analyze available Willamette and Columbia River flow records to estimate 100-year return intervals and determine whether the Lower Willamette Group (WLG) estimate of 360,000 cfs (10,194 m^3/s) as the 100-yr flow event for the Willamette River at Portland is reasonable.

It is difficult to determine flows associated with specific return intervals, e.g., 100yr flows, for the Willamette and Columbia Rivers for at several reasons:

- Management and climate both affect flows, and both have changed/are changing. The period of major reservoir construction for both the Willamette and Columbia Rivers extended from the 1930s to the 1970s. The present management system has been in place for only about 40 years, which is a very short time period for estimation of flood flow probabilities.
- The time period of the modern management regime (since the 1970s) is short relative to the most relevant climate cycle, the Pacific Decadal Oscillation or PDO. To obtain a reasonable number of peak flows and assess inter-decadal variability in peak flows, it is necessary to encompass at least the time period since 1948 [Naik & Jay, 2011], but preferably longer.
- The flood risk is non-stationary. Climate change is affecting and has affected the flow cycle in both systems, altering the character and frequency of occurrence of extreme flows [Hamlet & Lettenaier, 1999a,b; Adam et al., 2009; Jay & Naik, 2011]
- The length of record (LOR) for the most relevant US Geological Survey (USGS) river gauging stations, the Columbia River at Beaver (since 1991) and the Willamette River at Portland (since 1972), is short enough to provide difficulties is estimating the probabilities of flood flows.

It can also be difficult to reconstruct actual LCR flows for specific floods before installation of the USGS Beaver gauge in 1991, and to gauge the impact of flood control by reservoir management. A series of recent papers has examined LCR flow records, and attempted to separate human and climate-change impacts on actual, observed flows [Bottom et al., 2005; Naik & Jay, 2005, 2011; Jay & Naik, 2011]. Sherwood et al. [1990] and Simenstad et al. [1993] document system management history.

<u>Columbia River Hydrology and Flood Return Intervals</u>

USGS has measured Columbia River flow at The Dalles daily, 1878-date, with annual peaks available since 1858. USGS has measured LCR flows daily at Beaver Army terminal during 1969-1970 and 1991-date. Naik & Jay [2011] have calculated routed daily flows for the LCR at Beaver for 1878-1991. Further information regarding flows in the LCR for ca. 1820-1876 is being developed by the author and Dr. Stefan Talke at Portland State University using historical research and application of the method of Rostamkhani et al. [2013] to the 1854-1876 Astoria tidal record. Naik and Jay [2011] concluded that there has been a decrease of ~17% (1878-1900 vs. present) in mean flows at The Dalles, and that this reduction is about half due to climate change and half due to diversion; logging has slightly increased flows (by 1-2%; Matheussen et al. [2000]), due to reduced evapotraspiration. Also, the Pacific Decadal Oscillation (PDO), with a typical period of about 50 years, has major effects on CR flows. Thus, it is important to include a time period that encompasses representative PDO variations in an extreme flow analysis. Furthermore, variability of flows is increasing: the two lowest flows occurred in 1977 and 2001, and 5 of the 10 wettest years (as estimated from annual average virgin flow) have occurred since 1950, despite an overall drying trend [Jay & Naik, 2011].

Estimated virgin flows (the flows that would have occurred, in the absence of diversion and flow regulation by dams) are important in understanding extremes. Jay & Naik [2011] conclude that the most extreme virgin high flows have changed little, even though the reservoir system has been very successful in preventing observed flows from reaching the high levels recorded before about 1970. It may seem odd that the virgin peak flows have not decreased despite a substantial decrease (~17%) in mean flows and a >40% decrease in observed peak flows. The reason for this apparent anomaly is that the snow pack now melts earlier and more rapidly than was historically the case. In the 19th century, a large spring freshet was usually a drawn-out matter than sometimes lasted until early September, e.g., in 1880. However, the most extreme known flood in the system, that of June 1894 (34,800 m^3/s or 1,230,000 cfs at The Dalles) combined the largest snowpack of any year since 1878 [as judged by the annual average flow] with a rapid, rain-induced spring melt, resulting in a very extreme event. The most similar recent flood to 1894 was the June 1948 event (28,300m^3/s or 999,400cfs) that destroyed Vanport, OR. Potentially severe spring floods in 1956, 1972, 1974, 1997 and 2011 were at least partially controlled by the reservoir system.

The success of the reservoir system since 1970 in controlling floods may suggest that only the post-1970 period be used in evaluation of extreme flows. This is incorrect for at least two reasons:

- The strength of the effect of climate cycles on Columbia River flow requires consideration of at least 1946-date, and given the available flow record, as long a record as possible. I have elected to use records back to 1946.
- Given a warmer climate and generally more rapid spring snowmelt, it is by no means certain that a future event of the scale of 1894 or 1948 (the Vanport flood) can be controlled by the reservoir system. Even though winters are warmer than before 1900, years with very large snowpacks still occur (e.g., 1972 and 1974, and 1996 and 1997), and the potential for very rapid snowmelt has increased.

- Columbia River winter floods have become larger and more common since about 1960. Depending on the relative timing of peak flows in the Columbia at Vancouver and the Willamette River at Portland, flood volumes equivalent to June 1948 can occur in winter. In 1964, for example, USGS records Waanenen [1970] indicate that the Columbia River at Vancouver (550,000 cfs) and the Willamette River at Portland (443,000 cfs) peaked simultaneously at 0800 on 25

> December with a combined flow of 993,000 cfs or 28,120 m^3/s. This simultaneous peaking of the two rivers is probably unusual but not unique.[1]

Explaining the uncertainty with respect to LCR flood control also requires understanding the nature of extreme events like 1894 and 1948. The history of the 1948 and 1894 floods has been reviewed by Paulsen [1949] and Nelsen [1949]. The 1948 Vanport flood of 28,300m^3/s or 999,400cfs was Oregon's "Katrina Moment." A dike break on 30 May 1948 demolished what was then Oregon's second largest city and flooded the Portland Airport. Water levels continued to rise for two more days, flooding large areas in Portland, including those in downtown, due to backwatering of the Willamette River by the Columbia River. A recurrence of this flood would cause many billions of $ of damage. Up to 1 May, 1948 was a relatively normal water year, though colder than average (but not as cold as 1950 and several other years during the cold PDO of 1947-1976). Heavy rain plus sudden warming in mid-May turned a normal year into a disastrous flood. May-June rainfall was 150-400+% of normal in Central Washington; this is about a ~3% event for the area (i.e., could be expected to occur 3X per century). This rainfall could not be controlled by the reservoir system (even if it occurred today), because it mostly occurred seaward of the bulk of the storage capacity of the system. A Corps of Engineers re-analysis of the 1948 flood indicated that a peak flow forecast made 15 April would predict ~40% of the actual flow on 1 June, using then current (ca. 1990) forecast tools [Speers et al., 1990]. Such a forecast would not be useful in controlling the flood.

Managing the reservoir system in spring remains a difficult, probabilistic exercise. Relevant factors include: a) reservoir system capacity above The Dalles is only ~40% of annual average flow; b) a large but variable fraction of the annual flow occurs during the spring freshet; and c) no mainstem dam below Grand Coulee has significant flood control capacity. Also, because the weather forecast is highly uncertain until ~7-10d before an event, reservoir capacity upstream cannot be used effectively to control large interior basin floods (like 1894 and 1948) with a large rain-on-snow component, because that would require beginning to empty reservoirs weeks in advance. Given inevitable uncertainty in weather and flow forecasts, this is usually not practical. Emptying the reservoir system too much in winter and spring risks very expensive water shortages in summer. Not emptying the system sufficiently risks flooding. Thus, very large floods remain a realistic possibility, as the ARkStorm exercise for California reminds us [Dettinger et al., 2013].[2]

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[1] Winter freshets are still, however, much shorter than spring freshets.

[2] The ARkStorm analysis is based on flooding that occurred in California in 1862. The winter of 1861-1862 was the most severe winter of the last 160 years on the West Coast of North America. The flood of record for the Willamette River occurred in December 1861, before the jet stream moved south to cause record flooding in California, from the Klamath River to the Los Angeles basin. It is believed that flooding of this sort is caused by series of "atmospheric rivers." An atmospheric river (AR) is a warm storm, usually of tropical origin, that sweeps across the Pacific with large amounts of moisture and strong winds. It can bring large amounts of rainfall across the coastline for several days at a time. A series of atmospheric river storms can cause major flooding. How severe the damage depends on unpredictable factors like whether fronts stall, and the location of successive ARs within a large basin. An AR storm in the headwaters of a system is followed by one closer to the ocean, reinforcing the flood bulge moving down river, can be much more severe than the opposite pattern. The unpredictable nature of such events and the complexity of their potential interactions with the reservoir system is a very good reason why a long record

The above discussion emphasizes that evaluation of future flood risks related to a recurrence of a Vanport-like event should consider both precipitation and flow patterns (Figure 4). Figure 4a shows that Columbia River Basin May-June precipitation has increased in recent decades, while annual average flows have changed rather little, though interannual variability has increased (Figure 4b). Also, the incidence of rain-on-events in the Interior Sub-Basin (east of The Dalles) has increased—there were only 4 large

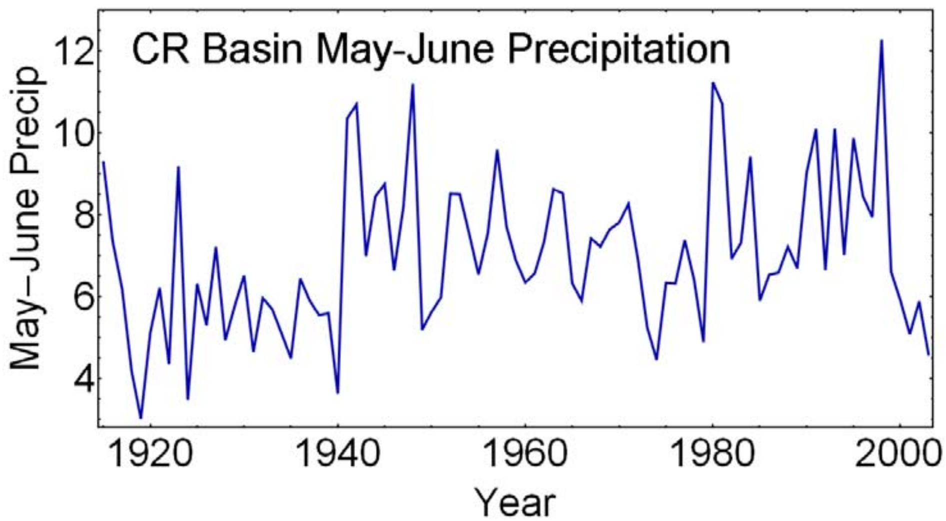

Figure 4a: Columbia River May-June precipitation, 1915-2004, from Deems and Hamlet [2010].

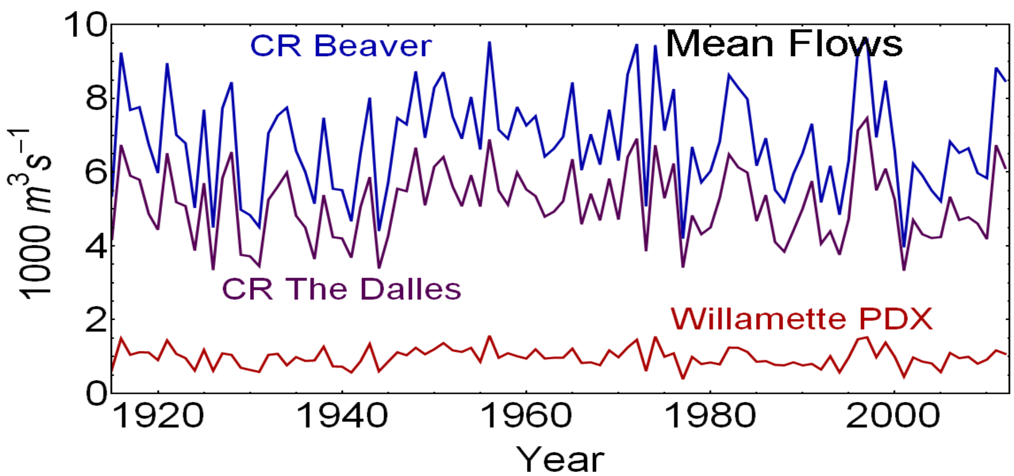

Figure 4b: Annual average flow at various Columbia River gauging locations, 1915-2012. Note the consistently high annual average flows during the 1947-1976 cold-PDO phase; during this period, only 1973 was unusually low.

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needs to be used to define return intervals for the Columbia River. Analysis of climate models suggest: a) greater irregularity in AR occurrence; i.e., more years with multiple AR storms and more years with no AR storms; and b) a greater incidence of such storms in fall and late winter [Dettinger, 2011]. The latter is potentially quite worrisome for Columbia River flooding, because it would increase the likelihood of very large rain-on-snow floods in the Columbia River Interior Sub-basin.

($>10^4$ m^3/s peak daily flow) winter rain-on-snow events east of the Cascades from 1860 to 1960, but there have been 8 since 1960. Because such events cannot be predicted, they pose a threat of a major flood in which the reservoir system is largely irrelevant. If a very large such event (similar to the December 1964 flood, but more prolonged) were to occur in late March on top of a large snowpack (e.g., 1974 or 1997), then a flood as large as 1948 or even 1894 could occur.

To summarize, the foregoing discussion: the different time scales of management and climate complicate estimation of 1% and 10% flow (essentially equivalent to 100 and 10yr recurrence intervals). There is, however, no justification for considering only the post-1972 flow record, as the higher flows that occurred prior to 1972 may well recur.

Return intervals for Columbia River flows at The Dalles, Bonneville Dam and Beaver

I have estimated flow return intervals for the Columbia River at The Dalles by applying Generalized Extreme Value (GEV) theory to the annual maximum observed (daily) flow, as implemented in the Mathematica programming system (Figure 5). GEV is a tool often used in hydrologic and extreme water level studies.[3] Figure 5 shows that using a realistic time period (1946-2012) instead of the modern (post-1970) record yields a much higher 100yr return flow: 27,200m^3/s (~960,000cfs) instead of 21,300m^3/s (~752,000 cfs). Use of the full flow record from 1878 forward would yield a yet larger estimate. Moreover, the actual occurrence of a flow in 1948 slightly larger than that estimated here (28,300m^3/s or 999,400cfs) supports this analysis. Extreme flows at Bonneville Dam, which are needed as a boundary condition in numerical modeling, are 100-200m^3/s higher than those at The Dalles.

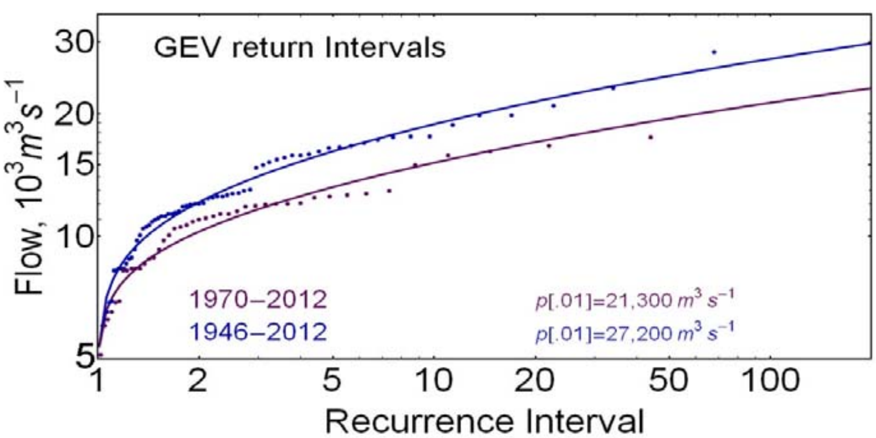

Figure 5a: GEV return intervals for Columbia River flow at The Dalles.

[3] There is a formal distinction between a 1% probability flow and the 100yr flood, but for present purposes, these can be treated as equivalent concepts.

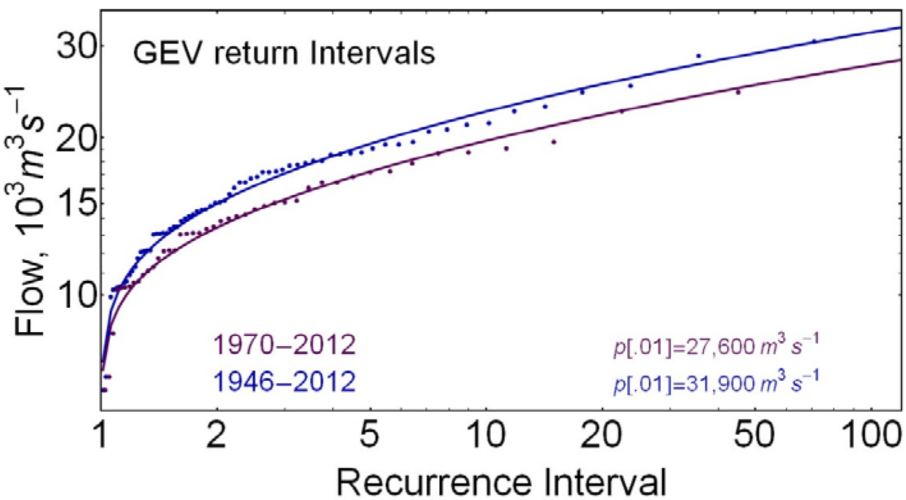

Figure 5b: GEV return intervals for Columbia River flow at Beaver Army Terminal.

It is important also to estimate extreme flows for the LCR at Beaver, because these are different from Columbia River flows at Bonneville Dam or even at Portland, due to the number of lower river tributaries. Flow from tributaries at least down to the Sandy River will affect backwater levels in Portland harbor. Application of similar methods to daily annual maximum estimated (daily) flow at Beaver Army Terminal emphasizes that flows in the LCR can be much larger than those at The Dalles (Figure 5b). Again, using a longer flow record (1946-2012 vs. 1970-2012) results in a higher estimate: 31,900m^3/s (1,120,000cfs) vs. 27,600m^3/s (974,700cfs). Also, the fit of the GEV curve is again quite good, and the 1948 flood falls essentially on the curve.

Willamette River Flood Hydrology

Portland Harbor has a long history of flooding, with the earliest historic Willamette River flood event dating to December 1813 [Brands, 1944]. Floods inundated the City of Portland at least once per decade until after World War II (Figures 6a,b). The remarkable aspect of the historic photos in Figure 6a,b taken in 1890 and 1894 is not just that flooding encompassed almost all of downtown and even reached the Park Blocks in 1894, but that Portland residents considered flooding so routine that they were equipped with boats to navigate city streets. Willamette River floods that were probably comparable to or greater than the December 1964 and February 1996 floods occurred in 1813, 1843, 1844, 1850, 1853, 1861, 1881 (two events), 1890, 1896, 1901, 1903, 1907, 1909, 1923 and 1943, with lesser events in 1873, 1877, 1894, 1927, 1936, 1948, 1955, 1974, 1995, and 1997 among others. In addition, Portland Harbor is affected by backwater flooding in years with high Columbia River flows.

Average Willamette River flows have, like Columbia River flows, declined somewhat since 1900 (~11%). However, reservoir construction between the 1930s and 1970s probably played a smaller role in the system than for the Columbia River, because there are no mainstem Willamette River flood-control dams, and the reservoir capacity is a smaller fraction of the annual average flow. All major floods occur in winter, and with a few exceptions, floods in the systems are rain-on-snow events [Brands, 1944]. USGS observations for December 1964 and February 1996 indicate daily average Willamette River flows of

12,000 and 11,900m^3/s (424,800 and 420,200cfs, respectively) at Portland. The peak measured flow during the 1964 event was 12,540 m^3/s (443,000 cfs), but there does not seem to be an estimate of peak flow for 1996. Portland Water levels and reconstructions by flow routing (described by Naik & Jay [2011]) suggest that floods in 1881, 1890, 1896, 1901, 1903, 1907, 1909 and 1943 had peak flows between 11,900 and 12,900m^3/s (420,000 and 455,500 cfs). Moreover, the flood of January 1923 was about 14,300 m^3/s (505,000 cfs) at Portland. The volume of the December 1861 flood is poorly constrained, but was larger than floods that followed, perhaps about 670,000cfs (19,000m^3/s).

Long-term Changes in flooding and flood properties

A FEMA (Federal Emergency Management Agency) analysis summarize graphically most of the major known events (Figure 7 and Gregory et al [undated]). There were four events before 1900 (1813, 1861, 1881 and 1890) that were considerably larger at Albany than any since. Clearly, flood peaks after about 1910 are smaller and less frequent than those before 1923. Brands [1944] indicates that most

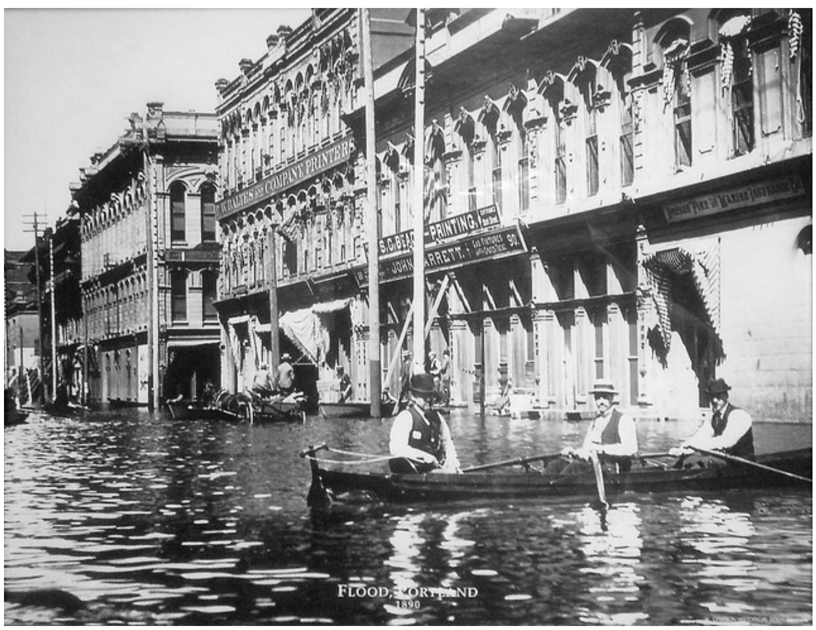

Figure 6a: Downtown Portland during the Willamette River flood of February 1890; note that the weather seems to have been mild in the aftermath of the flood. [From https://www.google.com/search?q=portland+1890+flood&client=firefox-a&hs=lts&rls=org.mozilla:en-US:official&channel=sb&tbm=isch&tbo=u&source=univ&sa=X&ei=aFB6VMCeHoS3oQTR4IDQBg&ved=0CFAQsAQ&biw=1513&bih=1030#facrc=_&imgdii=_&imgrc=_Pwkx-Zz61TUHM%253A%3BR9ONN6dbE8h_dM%3Bhttps%253A%252F%252Fc1.staticflickr.com%252F3%252F2827%252F12649384745_3b28486cdb_z.jpg%3Bhttps%253A%252F%252Fwww.flickr.com%252Fphotos%252F41894180030%2540N01%252F12649384745%252F%3B640%3B489, visited 28 November 2014].

Willamette River flood events have a rain-on-snow character, and those in 1964, 1974, 1996 and 1997 were of this sort. The decrease in the size of Willamette river flood peaks has likely been caused by a combination of flow regulation and climate change. A warmer climate might be less favorable for rain-on-snow floods, if it reduced the probability of accumulation of a large snowpack at the lower elevations of the Willamette Valley. While warming will likely reduce the probability of such occurrences at some point in the future, it is by no means clear that this has occurred up to the present. Considerable low elevation snowpacks accumulated, for example, in 1993, 1996, 1997, 2008 and 2014.

The Willamette River provides a highly non-stationary flood record, and some judgment is needed in estimating flood peaks. A very conservative choice in this regard emphasizes floods that do not involve rain on a low-elevation snowpack in the Willamette Valley. The January 1923 flood of about 14,300m^3/s (505,000cfs) is particularly noteworthy in this regard, because: a) it was generated primarily by very prolonged rainfall and was not a rain-on-snow-event [Brands, 1944]; b) it was large at Portland even by 19th century standards; c) such events are more likely in a warmer and wetter climate, as predicted for the Pacific Northwest; and d) the reservoir system, which traps runoff from the mountain snowpack, is fairly irrelevant to floods that do not involve extensive snowmelt.[4] There have been a number such events since 1844, as tabulated in Table 1, and more can be expected in the future, even if the climate warms.

Figure 6b: Flooding along the Park Blocks in Portland during the Columbia River flood of June 1894, which backwatered Portland Harbor, leading to severe flooding. [From https://www.google.com/search?q=portland+1894+flood&client=firefox-a&rls=org.mozilla:en-US:official&channel=sb&biw=1513&bih=1030&tbm=isch&tbo=u&source=univ&sa=X&ei=vlF6VNPuI8vmoASk7wE&ved=0CDAQ7Ak#facrc=_&imgdii=_&imgrc=P9Zeb7zvjkdSEM%253A%3Bx2M5MyHy7dEzcM%3Bhttp%253A%252F%252Fwww.oregonencyclopedia.org%252Fmedia%252Fuploads%252FPark_Blocks_North_Portland_during_flood_Jun_6_1894_1.jpg%3Bhttp%253A%252F%252Fwww.oregonencyclopedia.org%252Farticles%252Fwillamette_flood_1894_%252F%3B3525%3B2368, visited 28 November 2014].

[4] Note that the peak flow at Albany in 1890 was higher than that in 1923, but that the routed flow at Portland was higher in 1923 than 1890, reflecting the higher percentage of the flow coming from lower in the Willamette River Basin.

It is also important to note that the capacity of the Willamette River reservoir system is limited. While it did considerably reduce flooding in the rain-on-snow floods of 1964 and 1996, neither of these events involved the duration of precipitation seen in 1923. Thus, even with the reservoir system in place, a flood as large or even larger than 1923 is still possible. The duration of the hydrologic record is not sufficient to estimate the probability of occurrence of such an event.

Return Intervals for Willamette River flows at Portland

As with the Columbia River flows, it is important to use a record of adequate length to estimate the 10 and 100yr floods for the Willamette River at Portland (Figure 8). As a compromise between the need for a lengthy flow record that accounts for PDO cycles and a general decrease in flood volumes, a GEV analysis was carried out on the post 1920 annual peak flows. There have been four Willamette River events since 1920 with flows of 11,900 to 14,300m^3/s (420,000 to 505,000cfs). Accordingly, the 1% return flow estimated by GEV is 14,200m^3/s (501,500cfs). Given three peak flows >420,000 cfs in 1943, 1964 and 1996, the estimate of the 100yr flood (360,000 cfs) presented by LWG in Appendix La Section 2.2.3 and based on post 1972 USGS observations is not reasonable; it is low by about 35%. A more reasonably estimate of 450,000cfs was provided by in 2004 [WEST Consultants, 2004], also based on post 1972 USGS data. Given the earlier WEST Consultants estimate, it is unclear why LWG provided such a clearly incorrect result in Appendix La.

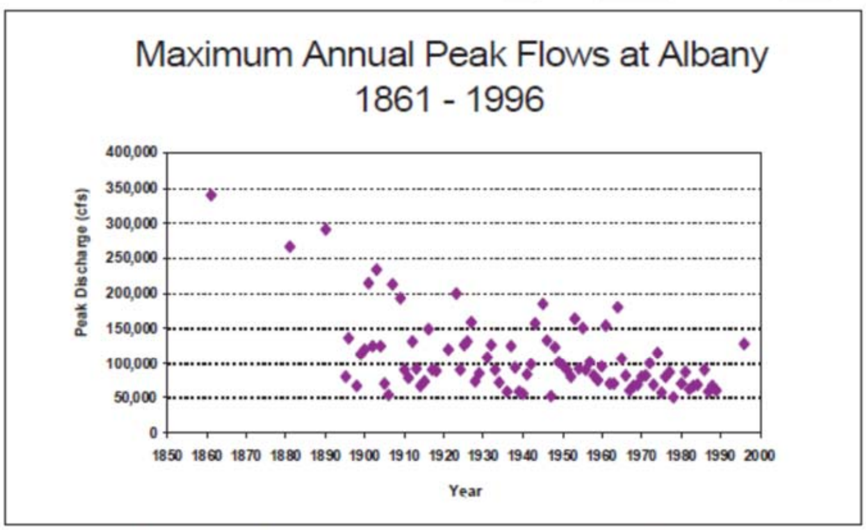

Figure 34. *Maximum flood discharges recorded at the Albany gauge from 1861 to 1996. The Albany gauge has the longest flow record on the Willamette River. Some years, such as 1907 or 1938, had three or four flooding events with flows greater than 50,000 cfs. Only floods greater than 50,000 cfs and only the largest flows in a given year are plotted.*

Figure 7: A summary of FEMA estimates of Willamette River floods between 1860 and 2000, based on the gauging record at Albany [Gregory et al, undated http://www.fsl.orst.edu/pnwerc/wrb/Atlas_web_compressed/3.Water_Resources/3e.flood&fema_web.pdf, accessed 28 November 2014]. Flows amounts are considerably smaller than at Oregon City or in Portland Harbor.

Summary of 10 and 100-year flood flows

Table 1 Summarizes estimates of 100-year flows for the Columbia River at The Dalles, at Bonneville Dam, and at Beaver Army Terminal, and for the Willamette River at Portland. The 100-year flood flows were determined by the GEV analysis described above. Consideration of the flood record for each location emphasizes that the 100-year flood estimates are by no means extreme, because at each location, there has been an event of the magnitude of the 100-yr flood in the last century and multiple such events in the last 120-160 years. A different, more conservative methodology was used to estimate the 10-year flood; the 10-year is taken as the seventh highest flood over the last 70 years (1933-2012). This approach was used because the Corps of Engineers manages the mainstem Columbia River specifically to avoid flows above about 600,000cfs, which introduces a discontinuity into the extreme-value time series. The procedure adopted provides a 10-year flow estimate that says, essentially, that this flow target will be reached (or slightly exceeded) once per decade.

Table 1: Early Season Willamette River floods, with Estimated or Measured Flows at Portland[1]

Year and date	Flow m^3s^{-1} and CFS
November 1844	Unknown, but <1890 (13,950 or 492,600 in 1890)
December 1861	19,000(?) or 670,000(?)
November 1896	10,200 or 360,000
November 1909	12,200 or 430,000
November 1921	9420 or 332,500
January 1923	14,300 or 505,130
November 1950	5693 or 201,040
November 1953	5576 or 196,900
November 1960	6510 or 229,750
November 1996	6030 or 212,980

[1] Flows are taken from Brands [1944] or other historical estimates, or routed as per Naik & Jay [2011] for 1896 to 1960. After 1960, values are USGS daily flow estimates. November peaks are assumed to be primarily rainfall driven. Information in Brands [1944] and newspaper accounts confirm that peaks in 1844, 1861 and 1923 were rainfall driven, not rain-on-snow.

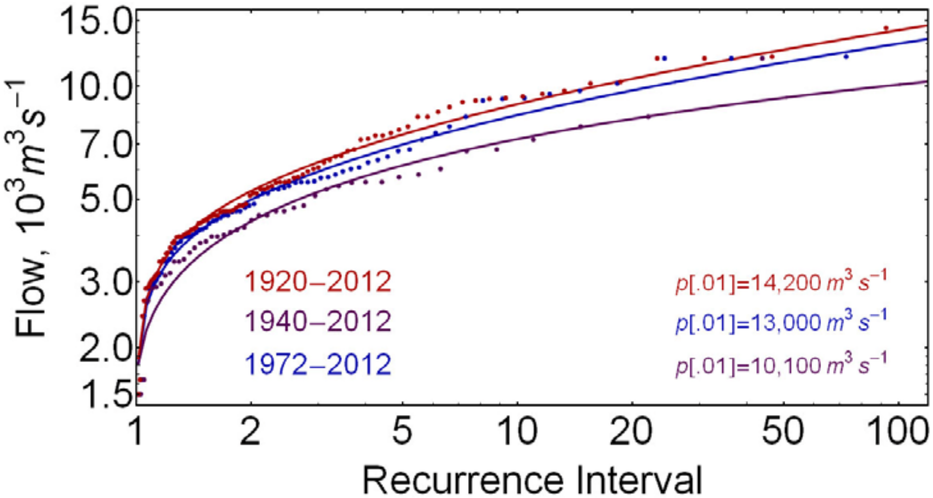

Figure 8: GEV return intervals for Willamette River flow at Portland.

Table 2: Flows and Return Intervals[1]

River and Location	Average Flow m^3s^{-1} CFS	10-Year Flood m^3s^{-1} CFS	100-Year Flood m^3s^{-1} CFS	Flood of Record m^3s^{-1} CFS
Columbia River at The Dalles	5280 186,500	17,600 622,000	27,200 960,500	June 1894 34,800 1,230,000
Columbia River at Bonneville Dam	5440 192,100	17,950 634,000	27,350 966,000	35,300 1,246,000
Columbia River at Beaver Army Terminal	7040 248,600	21,320 753,000	31,900 1,126,500	June 1894 38,600 1,316,000
Willamette River at Portland	1000 35,300	9300 328,500	14,200 501,500	Dec 1861 >19,000 670,000

[1] As noted in the text, there is a formal distinction between the 1% or 10% flow occurrence estimated by the GEV method and the 100 and 10 year return intervals, but the difference is small in practice.

Summary

This analysis has provided estimates of 10 and 100-yr return flow for the Willamette River at Portland and the Columbia River at The Dalles, Benneville Dam and Beaver, as summarized in Table 1. The 100-yr flood estimate for the Willamette River at Portland provided by LWG (360,000 cfs or) is about 1/3 less than a more realistic estimate (14,200 m^3/s or 501,500 cfs) provided here via a GEV analysis. The differences between these two estimates are caused by: a) methodology, and b) the use of an artificially and unjustifiably short analysis (since 1972) by LWG. It should be noted that WEST Consultants [2004] used a method similar to LWG for the same post-1972 time period and arrived at an estimate of 450,000 cfs or (12,700 m^3/s). My estimate of 14,200 m^3/s or 501,500 cfs is supported by the occurrence of 4 flood peaks between 420,000 and 505,000 cfs since 1923, a period of 90 years. It is also not justifiable to ignore flood peaks before completion of the reservoir system in the 1970s, because very large historical floods like 1844, 1861 and 1923 would not have been controlled by the reservoir system. They involved lengthy periods of intense precipitation, not the melting of a low elevation snowpack that could be partially controlled by the reservoir system. Also, rain-on-snow events can still occur, because a low-elevation Willamette Valley snowpack still occurs in some years, and the reservoir system could be overwhelmed by the combination of snowmelt and prolonged precipitation.

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